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Islands ecological integrity evaluation using multi sources data

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ABSTRACT

The islands located adjacent to the mainland provide us a lot of natural resources supported by their specific ecosystem structure and function, but they are easy to suffer from anthropogenic pressures and environmental change impacts. The island ecological integrity evaluation is one of the useful tools for the island protection and management. In this study, we proposed the island ecological integrity concept and developed a multi spatial and temporal scale evaluation index system, including anthropogenic pressures, climate change impacts, ecosystem function, and ecosystem structure. We applied the method and used the multi sources data to evaluate the ecological integrity in Nanri island, Dongan island, and Chuanshi island in Fujian Province, China in 2006 respectively. The result showed that the I_{ACEE} scores were 0.61, 0.55 and 0.60 in Dongan, Chuanshi and Nanri islands respectively. The I_{AP}, I_{CC}, I_{EF} and I_{ES} scores were 0.72, 0.71, 0.43 and 0.54 in Dongan island; 0.71, 0.70, 0.40 and 0.39 in Chuanshi island; 0.67, 0.58, 0.41 and 0.62 in Nanri island respectively. The results indicated that the indexes system could reveal the islands ecological integrity on different spatial scales and spatial locations.

1. Introductions

Islands are very important nature resource pool because they cover diverse ecotypes, enriching the biodiversity on earth (Lagbas and Habito, 2016). They locate in the transitional zone with strong interaction in the ocean-terrestrial-atmosphere biosphere circle, the edge effect is obvious, the environmental gradient is large, the self-organization ability and self-recovery ability are weak (Wu et al., 1992). The islands near the mainland are important to human. They have economic, cultural, scientific, military and political values, which provide precious ecosystem services such as marine fishery production, primary production, wetland ecosystem gas regulation, ocean ecosystem waste disposal, and public education (Aretano et al., 2013). However, anthropogenic pressures and climate changes were easy to result in species invasion, habitat change, biodiversity lost in the islands (Garcia et al., 2017; Simaiakis et al., 2017). There is a need to quantitatively assess the environment influences on near the mainland islands.

Island ecosystem assessment has been applied to the islands' eco-environment protection and management. Qiu et al. (2007) assessed the ecological vulnerability of the western Hainan Island of China using a combined approach of landscape pattern and ecosystem sensitivity, and the evaluation framework included reciprocal of fractal dimension, isolation, fragmentation, sensitivity of land desertification, and sensitivity of soil erosion. Santos Gomez (2013) found adaptive trade-offs in length-weight allometry might reduce vulnerability under climate change of adult ground beetle assemblages in their original elevation stratum on Tenerife, which could assess the natural assemblages vulnerability and resilience. Gilman et al. (2014) evaluated the Marshall Islands longline tuna fishery ecological risks through a consideration of phylogenetic uniqueness, risk of population extirpation, risk of species extinction and importance in ecosystem regulation. Kurniawan et al. (2016) studied the level of vulnerability in small islands to tourism as a basis of integrated small islands management in Indonesian conservation area, and the vulnerability index included the coastline, coral reef, live coral reef, and development area. Shope et al. (2016) used near-surface wind fields from four atmosphere–ocean coupled global climate models (GCM) under representative concentration pathways (RCP) 4.5 and 8.5 to stimulate future wave climates of 25 tropical Pacific islands and found it will be necessary to assess island vulnerability under climate change in future studies.

Ecological integrity evaluation is one of the important means to resource management and environment protection, especially under the increasing influence of climate change and human activities. There were many ways by which we could understand the meaning of ecological integrity (Miller and Ehnes, 2000). One was ecosystem composition factors, which means an ecosystem reaches its optimum status at the specific geographic region. Thus, ecosystem would possess all the native biodiversity and ecological process that regional natural habitat

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should contain, the ecosystem structure and function not damaged by the human activities pressures, and the native species would reproduce sustainably (Karr, 1993; Woodley, 1993). Another was ecosystem characteristics, which included health, resistance, recover and self-organization ability (Andreasen et al., 2001). The self-organization inner process of the ecosystem also manifested that if an ecosystem could maintain its organization structure, stable status, resistance ability and recover ability, it is an integral ecosystem (Mller et al., 2000).

There were many concepts about ecological integrity. The similarities were ecological integrity includes structural integrity and functional integrity, and an integral ecosystem is self-sustaining, self-renewable (Karr, 1981; Castela et al., 2008). The differences were the consistency object they emphasis, such as the rate of ecosystem process, the selection of reference environment and the consideration of multi scales (Castela et al., 2008; Jiang et al., 2015; Rempel et al., 2016). For examples, Jiang et al. (2015) proposed an estuary wetland ecosystem has ecological integrity if its lands, waters, living beings and ecological structure and function are intact in different spaces and scales under pressure and can sustainably provide ecosystem service to humans. Rempel et al. (2016) proposed ecological integrity of managed forests includes the ability of an ecosystem to support a community of organisms with a similar species composition and functional organization as found in nearby natural systems.

To some extent, single disciplinary perspective has limitation in understanding ecological integrity. The large scale study mainly focus on the influence of climate factors on the ecosystem, which reflects the overall change of island macroscopically. While the small scale study mainly studies the individual behavior in the ecosystem, which shows the complexity and diversity within the island. If we use a single factor to evaluate the ecological integrity, the result is easy to influence by the personality of the factor. If we use a multi-perspective approach to evaluate the ecological integrity, the condition of the ecosystem could reflect objectively and comprehensively. Thus, we proposed the ecological integrity should comprehensively consider the multiple factors in study region, such as the spatial scale, spatial location, the physical, chemical and biological factors, as well as the interior condition and external influence of ecosystem.

The ecological integrity evaluation has been applied to many ecosystems e.g. river, wetland, estuary, coastal zone and forest by researchers. For examples, Broeck et al., (2015) reviewed the abiotic and biotic indicators that applied to the evaluation of freshwater habitats ecosystem integrity. In which, the abiotic indicators included nutrient concentrations, ion, PH, as well as chemical and biological oxygen demand. abiotic indicators included vertebrates, macroinvertebrates, zooplankton, macrophytes and phytoplankton. Chin et al. (2015) compared different methods for generating indices of biotic integrity for Great Lakes coastal wetlands using bird community data, and the methods included rank sum and multivariate approaches for defining landscape disturbance gradients, generalist-specialist, multimetric and probabilistic. Jiang et al. (2015) developed a multi-scale estuary ecological integrity evaluation index system including environmental quality, biology and ecology, landscape pattern and ecosystem management based on dissipation theory. Golfieri et al. (2016) choosed odonates as bioindicators for the ecological integrity of the river corridor, and developed the Odonate River Index based on the Odonate Habitat Index to assess the conditions of the whole corridor in alluvial rivers. Rempel et al. (2016) developed an ecological integrity indicator system based on simulated natural disturbance and indicator species to test the forest condition and habitat in managed forests, and the selected indicators included habitat function and forest condition.

In this study, we proposed the concepts of the near mainland islands ecological integrity, and built a multi scales island ecological integrity comprehensive evaluation index system that adapted to near mainland islands, including anthropogenic pressures, climate change impacts, ecosystem function, and ecosystem structure. We took the Dongan island, Chuanshi island and Nanri island in Fujian Province, China as examples and studied its ecological integrity in 2006 using a comprehensive evaluation method, with the support of field measurements data and multi sources remote sensing data. The study provided a theoretical basis for the island protection and management.

2. Methods

2.1. Comprehensive evaluation index system

2.1.1. Islands ecological integrity concepts

The island ecological integrity should consider the space location and scale heterogeneity in island ecosystem. For space location,

Table 1
Island ecological integrity evaluation framework.

Hierarchy 1	Hierarchy 2	Hierarchy 3	Hierarchy 4
A1 Ecological integrity	B1 Anthropogenic pressures	C1 Marine environmental quality	D1 Inorganic nitrogen (DIN)
			D2 Inorganic phosphorus (DIP)
			D3 Chemical Oxygen Demand (COD)
			D4 Petroleum
			D5 Eutrophication status index
		C2 Sediment quality	D6 Sulfide
			D7 Organic carbon
			D8 Petroleum (sediment)
		C3 Land use status	D9 Land use degree index
			D10 Landscape fragmentation index
	B2 Climate change impacts	C4 Precipitation	D11 Mean annual precipitation
			D12 Mean annual precipitation change velocity
		C5 Temperature	D13 Mean annual temperature
			D14 Mean annual temperature change velocity
		C6 Natural disasters	D15 Red tide frequency
			D16 Typhoon frequency
	B3 Ecosystem functions	C7 Ecosystem resistance stability	D17 Landscape diversity index
		C8 Ecosystem recover ability	D18 Ecological elasticity index
		C9 Self-organization	D19 Energy capture
			D20 Exergy dissipation
		C10 Ecosystem vitality	D21 Net Primary Productivity (NPP)/Gross Primary Productivity (GPP)
	B4 Ecosystem structures	C11 Phytoplankton	D22 Diversity index
		C12 Zooplankton	D23 Diversity index
		C13 Intertidal benthos	D24 Diversity index
		C14 Shallow sea benthos	D25 Diversity index
		C15 Terrain	D26 Average land slope

Table 2
Basis for selecting the indexes.

Indexes	Basis for selecting the indexes
D1 ~ D5	The water qualities near shore were poorer than that offshore in Fujian Province (Fujian Province Marine Environment Bulletin in 2007–2016, published in 2008–2017). The eutrophication evaluation in the region around Sansha Bay, Minjiang Bay mouth and Nanri islands, Fujian Provinces showed that there were different levels of eutrophication in these regions (Zheng, 2010; Luo, 2011; Liu, 2013). The indexes indicate the impact of human activities on the water quality around the islands, which belong to local scale indexes.
D6 ~ D8	The indexes indicate the impact of human activities on the sediment quality around the islands, which belong to local scale indexes.
D9	The index can preferably reflect the integrated effect of natural and artificial factors of the land, as well as the intensive and extensive of land use. The index indicates the influence of human activities on the land of the islands, which belong to local scale indexes.
D10	The index characterizes the extent to which the landscape is fragmented and reflects the complexity of landscape spatial structure. The index could influence not only the species distribution and productivity level, but also the energy and nutrient distribution in land. The index indicates the influence of human activities on the land of the islands, which belong to local scale indexes.
D11	The index is one of the important factors affecting the bio-distribution of terrestrial ecosystems. Usually, in the drought condition, the higher the precipitation, the better for the ecosystem. However, excessive precipitation is disadvantageous to the ecosystem. The index indicates the influence of climate on the land of the islands, which belong to regional scale indexes.
D12, D14	The index reflects the influence of climate change velocity on the land of island ecosystem. The higher the change velocity, the higher the possibility of breaking the ecosystem equilibrium (Reice, 1994). The indexes indicate the influence of climate changes on the land of the islands, which belong to regional scale indexes.
D13	The index could influence the specie distribution in land ecosystem. Compared to coastal region, islands in Fujian were easy to suffer from drought. The higher the temperature is, the greater the evaporation is, which is disadvantage to the island ecosystem. The index indicates the influence of climate on the land of the islands, which belong to regional scale indexes.
D15	The lower the red tide frequency the better. The index indicates the influence of human activities on the ocean of the islands, which belong to local scales indexes.
D16	The lower the typhoon frequency the better. The index indicates the influence of climate on the land of the islands, which belong to regional scale indexes.
D17	Diversity can be quantified as landscape diversity index (H), which can directly show the ecosystem diversity variation and reveal the variation result of the ecosystem resistance stability. The index indicates the ecosystem function of island, which belong to local scale index.
D18	Ecological elasticity is the ecosystem's self maintenance ability, self regulation and resists all kinds of pressure and disturbance. It reflects the eco-environment characteristics and represents the ecosystem's recover capacity. The index indicates the ecosystem function of island, which belong to local scale index.
D19, D20	The stronger the self-organization a system possess, the stronger it has the ability to keep and produce new function. Lin et al. (2009) developed a set of thermodynamic indicators and used field measurement methods to quantify plant community self-organization in land. It is measured through energy capture ability by R_n/DR and exergy dissipation ability by the TRN. A more self-organized system will have higher values of both R_n/DR and TRN than an ecosystem with relatively lower self-organization. The indexes indicate the ecosystem function of island, which belong to local scale index.
D21	The index reflects the ecosystem vitality. The higher the ecosystem vitality the better. The index indicates the ecosystem function of island, which belong to local scale index.
D22 ~ D25	The indexes indicate the ecosystem structures of the ocean of island, which belong to local scale index.
D26	The bigger the slope, the bigger the possibility of soil and water loss. The index indicates the ecosystem structures of island, which belong to local scale index.

Table 3
Metrics of indexes.

Indexes	Metrics
D5	$$E=\frac{COD\cdot DIN\cdot DIP}{COD'\cdot DIN'\cdot DIP'}, \quad (1)$$ where E is the eutrophication index (Chen et al., 2010). If $E \geq 1$, the water is eutrophicated. COD′, DIN′ and DIP′ represent the thresholds of COD, DIN and DIP, respectively, in a sea region. According to China seawater quality standard (GB3097-1997). We obtained 3.0, 0.30 and 0.03 as the thresholds of COD′, DIN′ and DIP′ in study regions, respectively.
D9	$$LUI = 100 \times \sum_{i}^{n} A_i \cdot C_i \quad (2)$$ where, LUI is the land use degree index in study region (value range 100–400) (Liu, 1996). The bigger the LUI, the more intense the human influence on the region; n is the number of land use degree classifications, Ai is the classified area percentage of the i class land use degree of the study region and Ci is the weight of the i land use degree classification of the study region, which divided into 4 classes. The classification of each land use degree and its weight are according to Liu (1996) and Jiang et al. (2015).
D10	$$MPS = \frac{A}{N} \quad (3)$$ where, MPS is mean patch size index, MPS>0 (McGarigal and Marks, 1995). A is the total area of all the patches in the landscape. N is the total patch number. In general, the bigger the patch size, the higher the species diversity.
D17	$$H= -\sum_{i=1}^{m} (P_i \ln P_i) \quad (4)$$ where, H is Shannon diversity index (McGarigal and Marks, 1995). Pi is the occurrence probability of i land use type in the landscape, m is the number of land use type. Usually, if the value of H is bigger, the composition of landscape structure is more complex.

(continued on next page)

Table 3 (*continued*)

Indexes	Metrics
D18	$$ECO_{RES} = H\sum_{i=1}^{n} S_i \times P_i \tag{5}$$ where, ECO_{RES} is ecological elasticity (Zuo, 2002). Si is the area of land use type i; Pi is the weight of land use type i; H is the landscape diversity index. The land use weight of evergreen forest, deciduous forest, water body, permanent wetland, shrubbery, grassland, farmland, urban land, and bare land are 10, 9.5, 9, 8, 7, 6, 5, 2, and 1 respectively (Chi et al., 2007; Zuo, 2002). The bigger the value of ECORES, the bigger the ecosystem ecological elasticity is.
D19	$$R_n = DR-UR-(ULR-DLR) \tag{6}$$ where, R_n (net radiation) is the net energy that is gained by ecosystems, and represents the balance between upward and downward shortwave and longwave radiation flux of the land surface (Lin et al., 2009). DR is downward shortwave radiation (solar radiation), UR is upward shortwave radiation (reflected radiation), DLR is downward longwave radiation and ULR is upward longwave radiation. A higher value of R_n/DR implies higher ecosystem energy capture.
D20	$$TRN = \frac{\sum_{t1}^{t2} R_n \Delta t}{\Delta t} \tag{7}$$ where, TRN (thermal response number) is the buffer capacity of a system against incoming energy, which can be interpreted as the amount of radiation required to change one unit temperature as a logical metric for comparison of thermal properties across ecosystems (Luvall and Holbo, 1989; Lin et al., 2009). $\sum_{t1}^{t2} R_n\Delta t$ is the net radiation R_n over the time interval Δt; and Δt is temperature variation over Δt, chosen here to be 1 month. TRN.

differences in species distribution, landscape types and even environmental background values can be found. For space scale, ecosystem types and characteristics are different from micro to macro scope (Jiang et al., 2015). In additions, because island ecosystem is vulnerable to environmental change, the influence of climate change and human activities should also consider. Based on which, we proposed near the mainland islands have ecological integrity if the structure and function of the land, intertidal zone and water ecosystem in different scales are unimpaired by stresses from climate change and human activity.

2.1.2. Evaluation index system

We built the island ecological integrity comprehensive evaluation index system as is shown in Table 1. The system was divided into four parts: anthropogenic pressures, climate change impacts, ecosystem function and ecosystem structure. The index system was divided into four hierarchies: target, rule, element and indicator layers, which correspond to hierarchy 1(A), hierarchy 2 (B), hierarchy 3 (C) and hierarchy 4 (D), respectively.

2.1.3. Metrics of evaluation index

According to the ecological integrity concept of near the mainland island, the indexes reflect the structure and function of ecosystems and the influence of climate change and human impacts on ecosystems from different space and scale. The indexes taking into account the island land, coastal zone and ocean, from microscopic water quality and aquatic biodiversity to macroscopic landscape pattern and climate impact. The basis for selecting the indexes and the metrics of indexes were in Tables 2 and 3.

2.2. Evaluation methods

2.2.1. Index normalisation

Index normalisation was used to make itself comparable without dimension (Liu, 2008). In this study, we used membership function to normalise the indexes. This function is divided into increasing, decreasing and intermediate functions, and their formulas are expressed as follows:

$$Y= \frac{Y_2 - Y_1}{X_2 - X_1} \times (X-X_1) + Y_1 \tag{8}$$

$$Y= \frac{Y_1 - Y_2}{X_1 - X_2} \times (X - X_2) + Y_2 \tag{9}$$

$$\begin{cases} Y = \frac{Y_i - Y_1}{X_i - X_1} \times (X-X_1) + Y_1 (X < X_i) \\ Y = 1 (X=X_i) \\ Y = \frac{Y_i - Y_2}{X_i - X_2} \times (X - X_2) + Y_2 (X > X_i) \end{cases} \tag{10}$$

where X is the measured value of the index; X2 and X1 are the relatively large and small values of the indexes that are known, respectively; Y is the membership degree of the index; Y2 and Y1 are the membership degrees of X2 and X1, respectively; and Xi is the ideal value of the index. If X1 < Xi < X2, membership degree Yi will be the current maximum.

2.2.2. The indexes scores calculation for each hierarchy

In this study, we used the weight sum comprehensive evaluation (Formulas (11) and (12)):

$$I= \sum_{i=1}^{n} X_i \cdot W_i, \tag{11}$$

where I is the estuary ecological integrity index of the subsystems of environmental quality, biology and ecology, landscape pattern and ecosystem management; n is the number of indexes; Xi is the membership degree of the index i; and Wi is the weight of the index i, which is determined through analytic hierarchy process (AHP) method.

The comprehensive ecological integrity index is expressed as follows:

$$I_{ACEE} = I_{AP} \cdot W_{AP} + I_{CC} \cdot W_{CC} + I_{EF} \cdot W_{EF} + I_{ES} \cdot W_{ES} \tag{12}$$

where I_{ACEE} is the comprehensive ecological integrity index in the islands; I_{AP}, I_{CC}, I_{EF} and I_{ES} are the ecological integrity indexes of anthropogenic pressures, climate change impacts, ecosystem functions, and ecosystem structures in hierarchy 2, respectively; and W_{AP}, W_{CC}, W_{EF} and W_{ES} are their weights, respectively.

Table 4
Classification of the ecological integrity comprehensive evaluation.

	1	2	3	4	5
Scores	[0, 0.2)	[0.2, 0.4)	[0.4, 0.6)	[0.6, 0.8)	[0.8, 1.0]
Description	Bad	Poor	Moderate	Good	Excellent

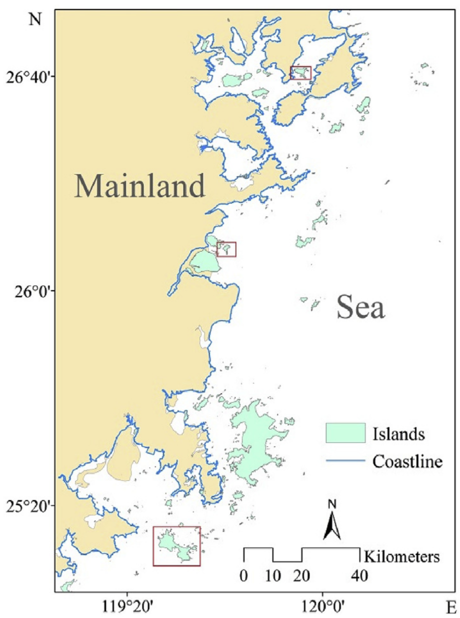

Fig. 1. Locations of the Dongan, Chuanshi and Nanri island.

2.2.3. Evaluation standard

The index evaluation is generated according to the subject judgment. According to Viana et al. (2012), the evaluation result of each index is divided into five levels (Table 4).

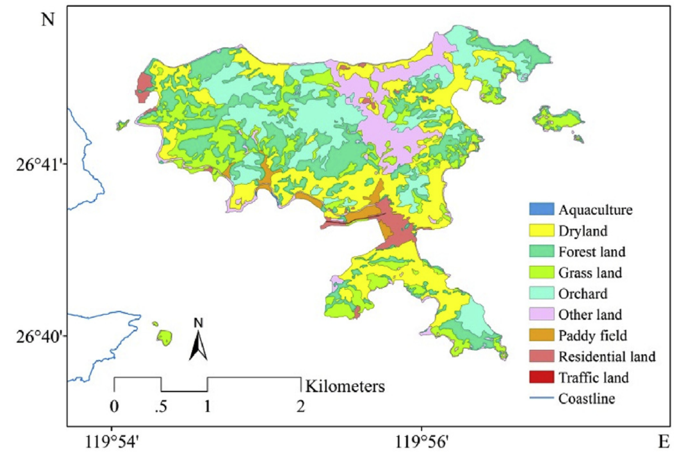

Fig. 2. Land use classification of Dongan island in 2006.

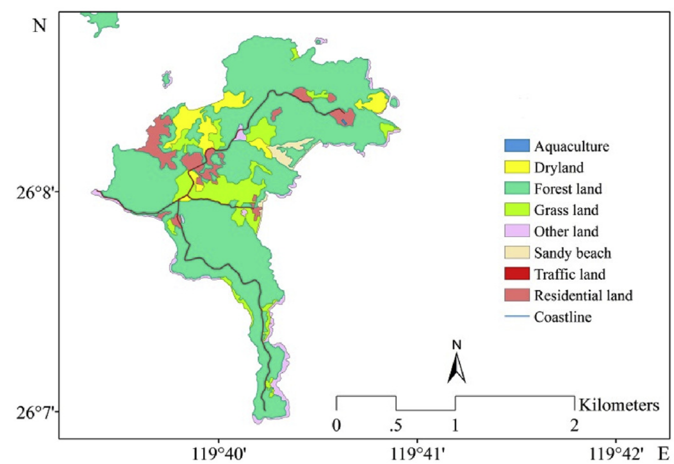

Fig. 3. Land use classification of Chuanshi island in 2006.

3. Data and process

3.1. Data source

3.1.1. Study region

We choose three small islands in Fujian Province, China as the case studies. These islands represented different latitude, geographical location and development level, but they were all continental island, bedrock island and village residential island. Locations of the islands as study regions with red marks are in Fig. 1. The general descriptions of the islands are in Table 5. In which, Dongan Island is of fertile soil, black pine and thatched grass. Its highest elevation is 277.2 m, shoreline length is about 22 km, population is more than 4,000, residents mainly engage in fisheries and agricultural cultivation. Chuanshi Island's highest elevation is 186.6 m, shoreline length is 12.96 km, population is more than 3000, residents mainly engage in mudflat aquaculture and offshore fishing, and it is rich in tourism resources. Nanri Island belongs to south subtropical marine monsoon climate. It is water scarcity, and its catastrophic weather is mainly typhoons, gale and rainstorm, population is more than 50,000, main industries are fisheries, tourism and energy industries.

3.1.2. Remote sensing data

The "Chinese offshore investigation and assessment" project, hereinafter called "908 special" project for short, provided the remote sensing investigation of the islands in Fujian Province. The islands land use data in this study were interpreted from the 2.5 m resolution SPOTS 5 panchromatic images in 2006, which were used to calculate the land use intension, ecosystem resistance stability, and ecosystem recover ability (Figs. 2–4). Aerial image, field investigation and historical information were used for remote sensing interpretation accuracy verification. "908 special" project also provided geomorphology and natural conditions data. The land use classification systems were according to the China land use classification standard and the remote sensing image interpretation capacity in the study region (Table 6).

Table 5
General situations of the islands.

Island	Location	Center Position Latitude and Longitude	Terrain Area/km^2	Main Characteristics
Dongan	In Sansha Bay	119°55′30.127″E, 26°41′4.694″N	6.64	Fertile soil, rich vegetation, abundant fishery resources, a certain degree of development.
Chuanshi	At Minjiang Bay mouth	119°40′8.346″E, 26°8′5.153″N	2.83	Rich in vegetation, rich in tourism resources, a higher degree of development.
Nanri	Outside Xinghua Bay	119°29′30.326″E, 25°18′17.454″N	42.10	Forest vegetation is less, rain shadow area, drought, have a certain degree of development.

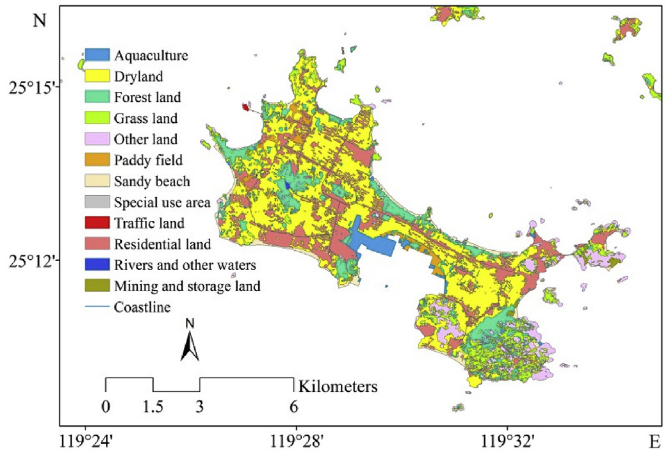

Fig. 4. Land use classification of Nanri island in 2006.

The land surface temperature in 2006 used MOD11 data from MODIS with 0.05° × 0.05° spatial resolutions and monthly temporal resolution were downloaded every month from http://modis.gsfc.nasa.gov/(Fig. 5).

The precipitation in 2006 with 0.25° × 0.25° spatial resolutions and monthly temporal resolution were downloaded every month from https://mirador.gsfc.nasa.gov/(Fig. 6).

The surface downwelling shortwave radiation and surface radiative net flux in 2006 with 1.00° × 1.00° spatial resolutions and yearly temporal resolution were from the Clouds and the Earth's Radiant Energy System (CERES) on board the satellite Terra and computed using MODIS-derived cloud properties and atmospheric properties through the Goddard Earth Observing System (GEOS-4 and 5) Data Assimilation System reanalysis. The download website is https://eosweb.larc.nasa.gov/(Figs. 7 and 8).

Net Primary Productivity (NPP) and Gross Primary Productivity (GPP) in 2006 used MOD17 from MODIS with 1 km × 1 km spatial resolutions and yearly temporal resolution. The data were taken from http://modis.gsfc.nasa.gov/.

3.1.3. Field measurement data

The investigation scopes of the islands are bounded by the underwater terrain turning point around the islands (Hu et al., 2014). The scopes of Dongan island, Chuanshi island and Nanri island cover 6.64 km^2, 2.83 km^2 and 42.10 km^2 of island land, and 11.29 km^2, 77.76 km^2 and 33.77 km^2 of sea area respectively. The data of the intertidal zone and offshore waters biology, seawater and sediments environmental qualities in 2006 were collected from the projects: "Report on the use of sea areas of 'kelp, seaweed' series of aquatic products deep processing projects sea reclamation project in Xiapu County, published in 2008", "Minjiang estuary marine environmental quality survey, published in 2009" and "Nanri island marine ecological construction and protection planning, published in 2007", and the nature disasters and island average land slope data come from "908 special" project (Hu et al., 2014).

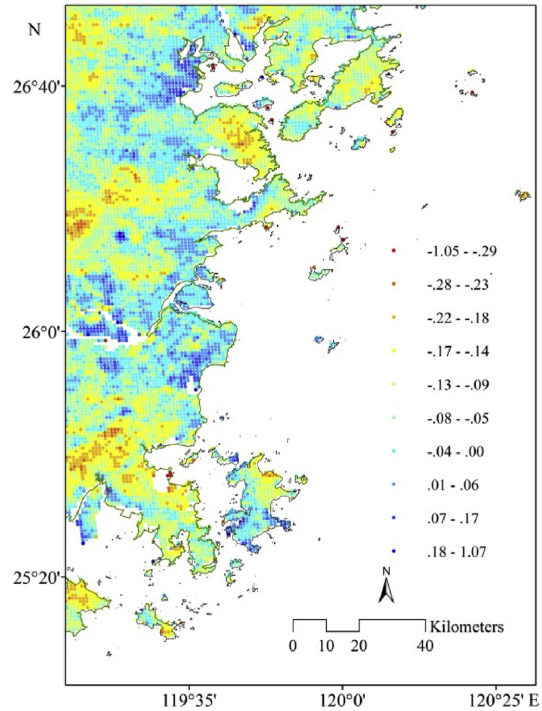

Fig. 5. Land surface temperature change during 2006 and 2016 (unit: K).

3.2. Weight of index

According to AHP method, indexes weight is shown in Table 7 (Liu, 2008; Ma, 2008; Qi, 2010; Wang, 2013; Hu et al., 2014).

4. Results

In this study, we took space as the dimension and compared the near the mainland islands ecological integrity in 2006 under the different environmental background and eco-environmental characteristics. In Hierarchy 4, the data sources of D5, D9 ~ D14, D17 ~ D21 were primary data, which were calculated by us. The others were secondary data, which were cited from Hu et al. (2014). The temporal scale of data was one year, which was the average value of all the data in the year.

Table 6
Land use classification in the three islands in 2006.

Land use types	Dongan		Chuanshi		Nanri	
	Area (km2)	Percentage (%)	Area (km2)	Percentage (%)	Area (km2)	Percentage (%)
Aquaculture	0.00	0.04	0.00	0.03	1.33	3.17
Dryland	1.63	24.52	0.15	5.41	17.21	40.87
Forest land	1.63	24.49	2.05	72.31	5.68	13.50
Grass land	0.92	13.88	0.27	9.64	3.27	7.78
Orchard	1.32	19.94	–	–	–	–
Mining and storage land	–	–	–	–	0.24	0.58
Other land	0.79	11.93	0.10	3.44	3.24	7.70
Paddy field	0.13	1.99	–	–	0.83	1.97
Residential land	0.21	3.14	0.17	6.01	8.32	19.77
Rivers and other waters	–	–	–	–	0.04	0.09
Sandy beach	–	–	0.04	1.47	1.57	3.72
Traffic land	0.01	0.08	0.05	1.69	0.35	0.84

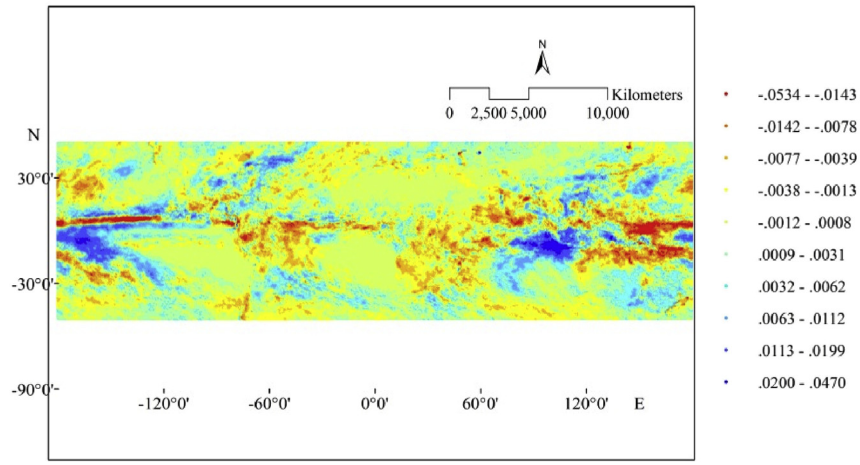

Fig. 6. Precipitation change during 2006 and 2016 (unit: mm/h).

The spatial scale of data was reflected by calculating the mean value of the factors in the study region.

We calculated the score of ecological integrity indexes in the three islands (Table 8, Figs. 9 and 10.). For hierarchy 1, the comprehensive ecological integrity index (I_{ACEE}) scores were 0.61, 0.55 and 0.60 in Dongan, Chuanshi and Nanri islands in 2006 respectively. The statuses of the ecological integrity in the three islands were good, moderate and good respectively. For hierarchy 2, the anthropogenic pressures (I_{AP}), climate change impacts (I_{CC}), ecosystem functions (I_{EF}) and ecosystem structures (I_{ES}) integrity scores were 0.72, 0.71, 0.43 and 0.54 in Dongan island; 0.71, 0.70, 0.40 and 0.39 in Chuanshi island; 0.67, 0.58, 0.41 and 0.62 in Nanri island respectively.

In Dongan island, the index values of Ecological elasticity index (D18), Energy capture (D19) and Exergy dissipation (D20) were poor. In Chuanshi island, the index values of Inorganic nitrogen (D1) was bad, and the Typhoon frequency (D16), Landscape diversity index (D17), Ecological elasticity (D18), Energy capture (D19), Exergy dissipation (D20), Zooplankton diversity (D23) and Intertidal benthos diversity (D24) were poor. In Nanri island, the index values of Exergy dissipation (D20) were bad, and the Inorganic phosphorus (D2) and Ecological elasticity (D18) were poor.

The indexes of the islands covered different spatial scales. The scores of temperature (D13), temperature change (D14) and typhoon (D16) that related to climate conditions are close to each other in the three islands, which showed the impact of these climatic factors on the islands were of regional scale. The scores of Inorganic nitrogen (D1) and Inorganic phosphorus (D2) in the three islands that related to

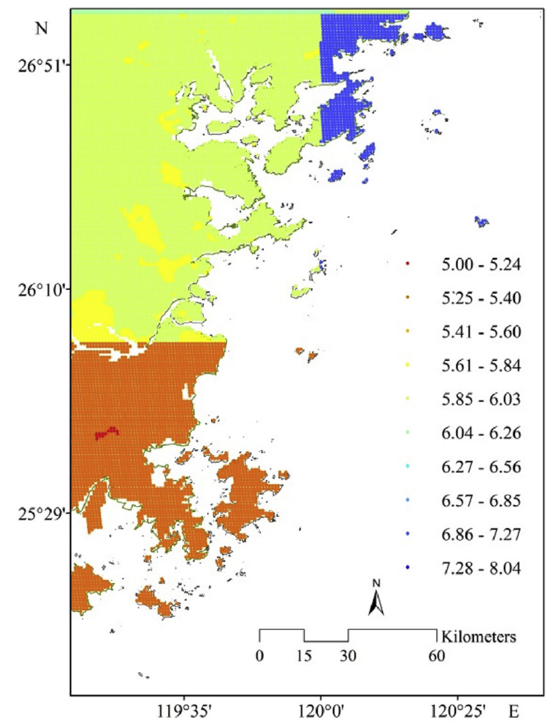

Fig. 8. Thermal response number in 2006 (unit: 24·3.6 KJ·m^{-2}·K^{-1}).

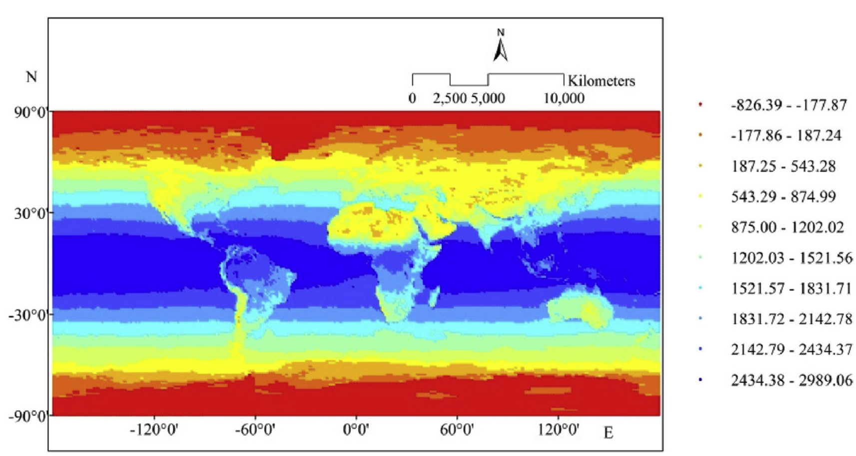

Fig. 7. Net radiation in 2006 (unit: W·m^{-2}).

Table 7
Indexes weight.

Hierarchy 2	Weight	Hierarchy 3	Weight	Hierarchy 4	Weight
B1 Anthropogenic pressures	0.39	C1 Marine environmental quality	0.25	D1 Inorganic nitrogen (DIN)	0.22
				D2 Inorganic phosphorus (DIP)	0.22
				D3 COD	0.11
				D4 Petroleum	0.12
				D5 Eutrophication status index	0.33
		C2 Sediment quality	0.25	D6 Sulfide	0.26
				D7 Organic carbon	0.48
				D8 Petroleum (sediment)	0.26
		C3 Land use status	0.50	D9 Land use degree index	0.50
				D10 Landscape fragmentation index	0.50
B2 Climate change impacts	0.11	C4 Precipitation	0.33	D11 Mean annual precipitation	0.60
				D12 Mean annual precipitation change velocity	0.40
		C5 Temperature	0.33	D13 Mean annual temperature	0.60
				D14 Mean annual temperature change velocity	0.40
		C6 Natural disasters	0.34	D15 Red tide frequency	0.50
				D16 Typhoon frequency	0.50
B3 Ecosystem functions	0.17	C7 Ecosystem resistance stability	0.23	D17 Landscape diversity index	1.00
		C8 Ecosystem recover ability	0.23	D18 Ecological elasticity index	1.00
		C9 Self-organization	0.32	D19 Energy capture	0.50
				D20 Exergy dissipation	0.50
		C10 Ecosystem vitality	0.23	D21 NPP/GPP	1.00
B4 Ecosystem structures	0.33	C11 Phytoplankton	0.15	D22 Diversity index	1.00
		C12 Zooplankton	0.15	D23 Diversity index	1.00
		C13 Intertidal benthos	0.44	D24 Diversity index	1.00
		C14 Shallow sea benthos	0.15	D25 Diversity index	1.00
		C15 Terrain	0.11	D26 Average land slope	1.00

Table 8
The ecological integrity index scores in the three islands.

Islands	I_{AP} (AP)	I_{CC} (CC)	I_{EF} (EF)	I_{ES} (ES)	I_{ACEE} (ACEE)
Dongan	0.72	0.71	0.43	0.54	0.61
Chuanshi	0.71	0.70	0.40	0.39	0.55
Nanri	0.67	0.58	0.41	0.62	0.60

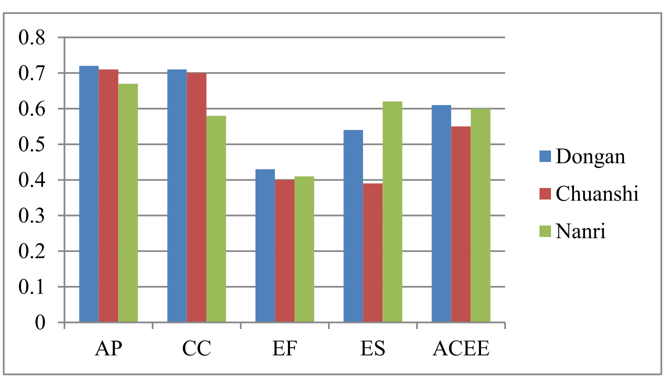

Fig. 9. The indexes score in the three islands in Hierarchy 2.

anthropogenic pressures were varied, which showed that the influence of nitrogen and phosphorus nutrients generated by human activities on the islands were of local scale.

The indexes of the islands covered different spatial locations. The common problems of the three islands in 2006 were the relatively low scores of Ecological elasticity (D18) and Exergy dissipation (D20) of ecosystem functions, which showed the weak resilience and self-organization capacity in the land ecosystems of the islands. The peculiar problems of Chuanshi island were the relative low scores of Inorganic nitrogen (D1), Typhoon frequency (D16), Landscape diversity index (D17), Zooplankton diversity (D23), and Intertidal benthos diversity (D24). The nitrogen concentration in the ocean of the island was relatively high under the influence of human activities. The land of the island was suffered from relatively intense typhoon frequency. The resistance stability of ecosystem function in the land ecosystem of the island was relatively low. The zooplankton diversity and intertidal benthos diversity of ecosystem structure in the coastal region and ocean of the island were relatively low. The peculiar problems of Nanri island were the relative low scores of Inorganic phosphorus (D2) and Mean annual precipitation (D11). The phosphorus concentration in the ocean of the island was relatively high under the influence of human activities and the drought was easy to happen in the land of the island.

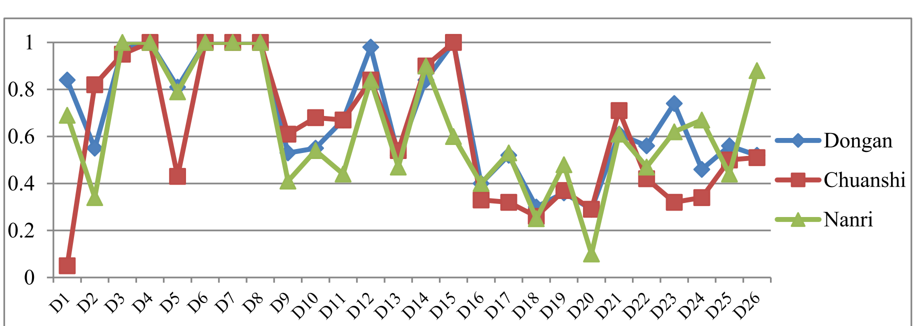

Fig. 10. Normalized values of each index in Hierarchy 4.

5. Discussions

We evaluated the ecological integrity in near the mainland island to provide a basis for the island protection and management. Near the mainland island ecosystems usually have different species distribution, landscape types and environmental background values in space, and different ecosystem types and characteristics from micro to macro scope. In additions, near the mainland island ecosystem is vulnerable to the influence of climate change and human activities. Thus, single disciplinary perspective could not understand the ecological integrity comprehensively.

A multi-perspective approach could use to evaluate the ecological integrity objectively and comprehensively. The large scale study mainly focus on the influence of climate factors on the ecosystem, while the small scale study mainly studies the individual behavior in the ecosystem. Considering the common factors of ecological integrity concepts that proposed in different literatures and the characteristics of near the mainland islands, we proposed the concept of near the mainland island ecological integrity concept: if the structure and function of the land, intertidal zone and water ecosystem in different scales in island are unimpaired by stresses from climate change and human activity, it have ecological integrity. According to the concept, we built the near the mainland ecological integrity evaluation index system. The indexes covered different spatial locations and spatial scales in the islands, including the biotic and abiotic factors, the ecosystem status of the island and influence of external factors on the island ecosystem.

Remote sensing data was usually convenient in revealing the large scale phenomenon and field investigation data was usually have advantage in studying the small scale phenomenon. Thus, multi sources data were used in this study to do the near the mainland ecological integrity evaluation. The remote sensing data used included SPOT 5 high-resolution images, MODIS product and CERES product. The data were in different spatial resolution, scale and acquisition time. In order to integrate them together, we calculated the average value of all the data in the year. Then, we calculated the indexes values using the temporal integrated data sources. Finally, we did the spatial scale integration of the calculated indexes values.

The comprehensive ecological integrity indexes (I_{ACEE}) scores in Hierarchy 1 showed that, the ecological integrity value of Chuanshi island was lower than Dongan island and Nanri island (Fig. 9). The ecological integrity indexes scores in Hierarchy 2 showed that, Anthropogenic pressures and Climate change impacts were not the main reasons that threatening the ecological integrity in the three islands. Ecosystem structures score in Chuanshi island was poor and much lower than that in Dongan island and Nanri island, which was one of the reasons that caused relative lower comprehensive ecological integrity in Chuanshi island. Ecosystem functions scores in the three islands were less than 5. Thus, enhancing the islands ecosystem function would help to increase the ecological integrity in the near the mainland islands. The study also showed that the similar indexes scores in different islands were not necessarily means their driving forces were the same. According to the land use in the three islands, the vegetation coverage was high and landscape diversity was low in Chuanshi island, and it was in contrast in Dongan island and Nanri island. However, the scores of Ecological elasticity index (D18) in the three islands were close.

According to the influenced space scale, the indexes could belong to local and regional indexes. The scores of Typhoon frequency (D13), Mean annual temperature change velocity (D14), Mean annual temperature (D16) in the three islands were close, which indicated the influence of temperature, temperature variation and typhoon on the islands were with regional scale. The scores of Chemical Oxygen Demand (D3), Petroleum (D4), Sulfide (D6), Organic carbon (D7), Petroleum (D8) were close and were all relatively high, which indicated the islands were suffer from relatively little these pollutions. The scores of Inorganic nitrogen (D1), Inorganic phosphorus (D2), Eutrophication status index (D5), Land use degree index (D9), Landscape fragmentation index (D10) varied among the three islands, which indicated the influence of these anthropogenic pressures on the islands were with local scale. In which, the inorganic nitrogen and phosphorus concentration variation could cause by different agriculture type, geographic location and hydrology condition in and around the islands.

According to the influenced space location, the indexes could belong to land, intertidal zone and ocean indexes. In which, D9 ~ D14, D16 ~ D21, D26 were the land indexes, and D1 ~ D8, D15, D22 ~ D25 were the intertidal zone and ocean indexes. The average values of the land indexes in Dongan, Chuanshi and Nanri island were 0.56, 0.53 and 0.54 respectively, and the average values of the intertidal zone and ocean were 0.79, 0.69 and 0.73 respectively. The indexes scores of the land were generally lower than the intertidal zone and ocean in the three islands, especially the Ecological elasticity index (D18), Energy capture (D19), and Exergy dissipation (D20). Vegetation is important to Ecological elasticity, Energy capture and Exergy dissipation (Zuo, 2002; Lin et al., 2009). Fresh water resources and vegetation restoration were what the three near the mainland islands need (Chen et al., 2016). The additional problems of Chuanshi island were the relative low scores of Inorganic nitrogen (D1), Typhoon frequency (D16), Landscape diversity index (D17), Zooplankton diversity (D23), and Intertidal benthos diversity (D24). The nitrogen concentration in the marine around the island was relatively high, the resistance stability and landscape diversity were relative low, and the zooplankton diversity and intertidal benthos diversity were relatively low. The additional problems of Nanri island were the relative low scores of Inorganic phosphorus (D2) and Mean annual precipitation (D11). The phosphorus concentration in the marine around the island was relatively high and the drought was easy to happen.

We did the multi-spatial scales ecological integrity evaluation in the near the mainland island using the multi-source data. In order to improve the accuracy of the evaluation results, we would obtain long time series data in the study regions and to build the big data model based on more diversified real-time observation data in the further study. In additions, it is necessary to carry out studies on the stability of indexes under special climatic conditions such as El Nino.

6. Conclusions

(1) We generalized the concepts of ecological integrity, proposed the island ecological integrity concept, and built the island ecological integrity evaluation framework, including Anthropogenic pressures, Climate change impacts, Ecosystem functions and Ecosystem structures. The index system was applied in the Dongan island, Chuanshi island and Nanri island.
(2) Results showed that the I_{ACEE} scores were 0.61, 0.55 and 0.60 in Dongan, Chuanshi and Nanri islands in 2006 respectively. The I_{AP}, I_{CC}, I_{EF} and I_{ES} scores were 0.72, 0.71, 0.43 and 0.54 in Dongan island; 0.71, 0.70, 0.40 and 0.39 in Chuanshi island; 0.67, 0.58, 0.41 and 0.62 in Nanri island respectively.
(3) We descript the problems of the three near the mainland islands based on the indexes scores, and the indexes system could reveal the islands ecological integrity on different spatial scales and spatial locations.

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